The IEEE *Standard on Transitions, Pulses, and Related Waveforms*, Std-181-2003

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***Abstract*—The IEEE has written a new standard on pulse techniques and definitions to replace the withdrawn standards IEEE Std-181-1977 and Std-194-1977. The new Std-181-2003 combines information from both of these withdrawn standards. Relative to the withdrawn standards, the new standard has incorporated new definitions, deleted and clarified previous definitions, provided examples of different waveform types, updated text to reflect electronic computation methods, and incorporated algorithms for computing waveform parameters. This paper introduces Std-181-2003 by describing its contents and changes relative to the withdrawn standards.**

***Index Terms*—Aberrations, IEEE Standard, overshoot, pulse amplitude, pulses, transition duration, transitions, undershoot, waveforms.**

I. Introduction

THE Subcommittee on Pulse Techniques (SCOPT) [1] of the IEEE Technical Committee 10 (TC-10, Waveform Measurement and Analysis) has, since 1996, been in the process of writing a new standard on terms, definitions, and algorithms for describing and computing waveform parameters that is based on two withdrawn IEEE standards: IEEE STD-181-1977, *Standard on Pulse Measurement and Analysis by Object Techniques* [2], and IEEE-STD-194-1977, *Standard Pulse Terms and Definitions* [3]. These withdrawn IEEE standards were adopted in 1987 by the International Electrotechnical Commission (IEC) and are the IEC 60 469-2, *Pulse Techniques and Apparatus, Part 2: Pulse Measurement and Analysis, General Considerations* [4], and IEC 60 469-1, *Pulse Techniques and Apparatus, Part 1: Pulse Terms and Definitions* [5].

The purpose of the new standard is to facilitate accurate and precise communication concerning parameters of transition, pulse, and related waveforms and the techniques and procedures for measuring them. Because of the broad applicability of electrical pulse technology in the electronics industries (such as computer, telecommunication, and test instrumentation industries), the development of unambiguous definitions for pulse terms and the presentation of methods and/or algorithms for their calculation is important for communication between manufacturers and consumers within the electronics industry. The availability of standard terms, definitions, and methods for their computation helps improve the quality of products and helps the consumer better compare the performance of different products. Improvements to digital waveform recorders have facilitated the capture, sharing, and processing of waveforms. Frequently, these waveform recorders have the ability to process the waveform internally and provide pulse parameters. This process is done automatically and without operator intervention. Consequently, a standard is needed to ensure that the definitions and methods of computation for pulse parameters are consistent.

The SCOPT is comprised of an international group of electronics engineers and physicists with representatives from national metrology laboratories, national science laboratories, the test instrumentation industry, and academia. The SCOPT meets two to three times a year to discuss terms describing waveform parameters, the definitions of these terms, and, if appropriate, algorithms for calculating values for those parameters. Interested knowledgeable parties are welcomed and encouraged to participate in future reviews and amendments to the standard and should do so by contacting the IEEE TC-10 chairman (see Section V for further information).

The new standard contains approximately 100 definitions. The purpose of this paper is to introduce the new IEEE standard by extracting the key and most technologically important terms and presenting their definitions and associated algorithms, if available. The most basic terms are given in Section II. Section III provides definitions of some waveform parameters, and Section IV contains some algorithms for finding the most frequently measured waveform parameters. Further discussion of this standard can be found in [6]. In Sections II–IV, the term to be discussed is provided in bold-face type and followed immediately by the definition of the term as taken from the Standard (within quotations). After the definition, a brief description of the term is given. References to clauses herein are references to clauses in the Standard.

II. Basic Waveform Terms

The basic terms typically do not have an associated algorithm as they are more descriptive.

Signal—"A signal is a physical phenomenon that is a function of time." This describes what is being measured and, as will be seen, is distinguished from a waveform.

Waveform—"A waveform is a representation of a signal (for example, a graph, plot, oscilloscope presentation, discrete time series, equations, or table of values). Note that the term waveform refers to a measured or otherwise-defined estimate of the

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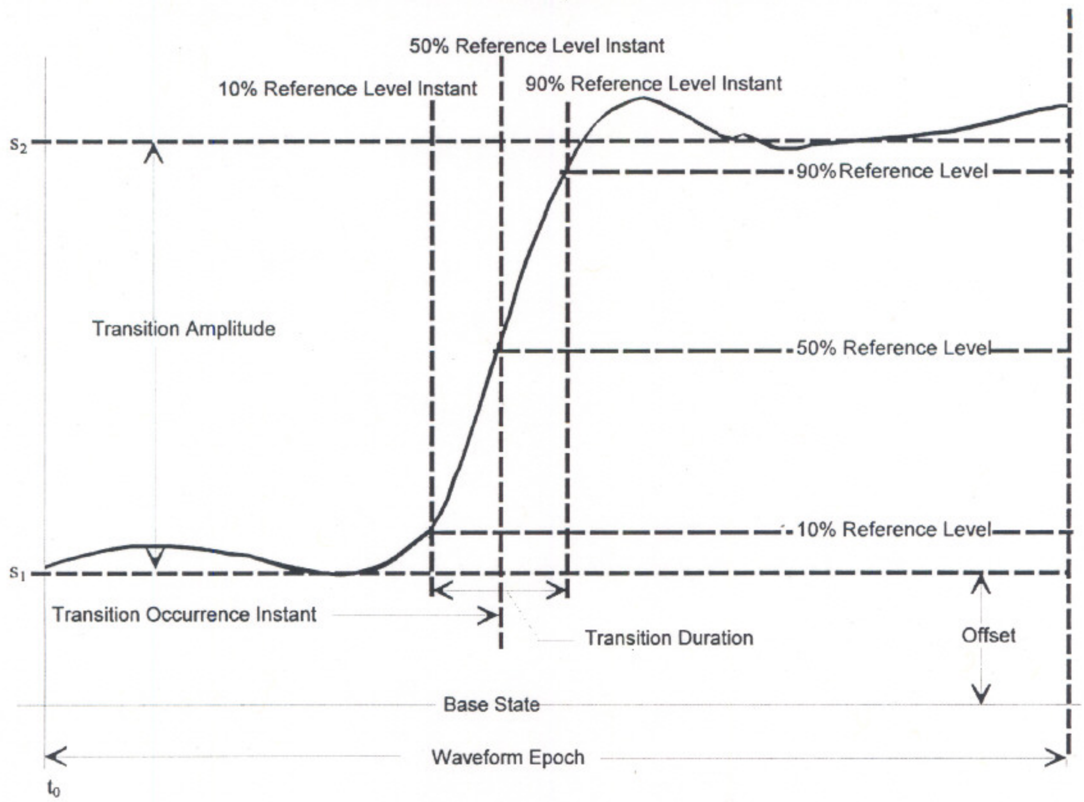

Fig. 1. Positive-going transition.

physical phenomenon or signal." Waveforms (see Fig. 1) are the things that are actually observed, acquired, and analyzed. The base state of a step-like waveform is a user-specified state that, unless otherwise specified, is the state that possesses a level closest to zero. The offset is the algebraic difference between two specified levels, such as the base state and s_1 (see Fig. 1). The transition amplitude, or transition waveform amplitude, is the difference between the two state levels of a transition waveform (see "waveform amplitude" in Section IV).

Compound Waveform—"A waveform which may be completely represented by m states and n transitions where $(m + n) \geq 4$. Any compound waveform can be parsed into n two-state waveforms." Compound waveforms are any waveforms that consist of more than two states, a high state and a low state, and more than one transition. Clause 5.5 of the Standard provides an algorithm for separating the waveform into a series of two-state waveforms from which all the defined parameters may be computed.

Pulse Waveform—"A waveform whose level departs from one state, attains another state, and ultimately returns to the original state (see Fig. 2). As defined here, a pulse waveform consists of two transitions and two states. Alternatively, a pulse waveform can be described as a compound waveform consisting of the sum of a positive (negative) step-like waveform and a *delayed negative* (positive) step-like waveform both having the same unsigned waveform amplitude." A pulse waveform is a compound waveform because it consists of two states and two transitions: a negative-going and a positive-going transition. In addition to being defined as a compound waveform, the Standard provides the above definition for a pulse waveform because it is one of the most commonly used compound waveforms. The pulse center instant is the average of two instants used to calculate the pulse duration. The pulse amplitude, or pulse waveform amplitude, is the difference between the two state levels of a pulse waveform (see "waveform amplitude" in Section IV).

Transition—"Contiguous region of a waveform that connects, either directly or via intervening transients, two state occurrences that are consecutive in time but are occurrences of different states." Transitions, in conjunction with states, comprise a waveform.

Negative-Going Transition—"A transition whose terminating state is more negative than its originating state. The endpoints of the negative-going transition are the last exit of the waveform from the higher state boundary and the first entry of the waveform into the lower state boundary." Positive-going transition is similarly defined. It is important to define negative-going transitions because of the confusion in how to describe waveforms that start at some level and then transition to a more negative level, where both of these levels must correspond to a state occurrence.

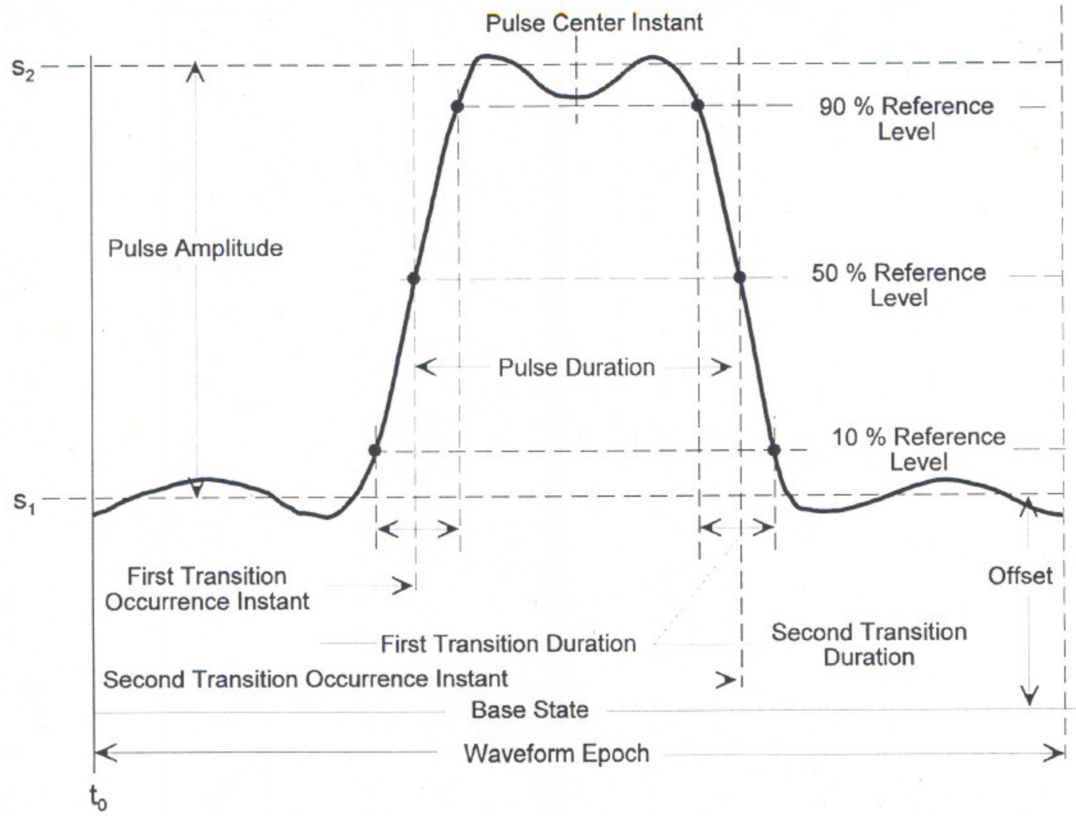

Fig. 2. Positive pulse waveform.

III. BASIC WAVEFORM PARAMETERS

The basic waveform parameters are fundamental to the description, discussion, and computation of all other waveform parameters. The basic waveform parameters do not require the definition or computation of other parameters, except for reference level instant. The Standard requires that the user specify the computation method used if more than one method is allowed, such as for states. Similarly, if more than one option is allowed for a given computational method, the user must specify the option used, such as using the 20% and 80% reference levels to compute transition duration instead of using the 10% and 90% reference levels. Reference level will be discussed in this section and transition duration in Section IV.

State—"A particular level or, when applicable, a level with an associated upper and lower state boundary. Unless otherwise specified, multiple states are ordered from the most negative level to the most positive level, and the state levels are not allowed to overlap. The most negative state is called state 1. The most positive state is called state n. The states are denoted by $s_1, s_2, \ldots, s_n$; the state levels are denoted by $\text{level}(s_1), \text{level}(s_2), \ldots, \text{level}(s_n)$; the upper state boundaries are denoted by $\text{upper}(s_1), \text{upper}(s_2), \ldots, \text{upper}(s_n)$; and the lower state boundaries are denoted by $\text{lower}(s_1), \text{lower}(s_2), \ldots, \text{lower}(s_n)$. States, levels, and state boundaries are defined to accommodate pulse metrology and digital applications. In pulse metrology, the levels of a waveform are measured and states (with or without associated state boundaries) are then associated with those levels. In digital applications, states are defined (with state boundaries) and the waveform values are determined to either lie within a state or not." This term is important because all level (voltage, current, etc.)-related parameters, such as amplitude, overshoot, and undershoot, are based on the states of a waveform. A state is a nominally constant-valued region of the waveform. In the withdrawn standards, the word *line* was used to describe the value corresponding to these nominally constant-valued regions of a waveform. Terms such as *topline* and *baseline* (or *bottom line*) were used. However, *line* is a graphical description and not an appropriate term for electronic computation of waveform parameters or for describing the output of a physical device. The term presented in the Standard is *state*. State is also consistent with the description of constant-valued currents or voltages from the output of actual electronic devices. States are numbered starting at the most negative and ending at the most positive and are designated by $s_1, s_2, \ldots, s_n$, where s_n is the most positive state and s_1 is the most negative state for an n-state waveform. For example, the waveform shown in Fig. 1 is a two-state waveform. Each state has an associated level that describes the value (number with units) for that state. For example, the two-state waveform in Fig. 1 can have $s_1 = 0$ V and $s_2 = 0.25$ V. Associated with a state are upper and lower boundaries, and a waveform is said to be in this state if its values are within these boundaries for a user-specified duration. The difference between the upper boundary and lower boundaries can be different for each state.

The Standard provides and/or identifies several methods for determining the levels associated with a state. These methods include those based on histogram methods (three are described), the extreme waveform values, the final and initial waveform values, user-defined values (which should be based on the user's knowledge of the device under test), static levels (if the pulse source can also output dc values to the same connector from which comes the output pulse), and auxiliary waveforms (in the case where there is insufficient data in one waveform to compute all the desired waveform parameters). The histogram techniques may use different bin sizes, and the user may select if the histogram modes, means, or medians will be used. The effect of different histogram implementations have been described elsewhere [7]. This study [7] does show that only for pathological cases will there be a noticeable difference among the results from the different methods.

High and Low State—"Unless otherwise specified, the high state of a waveform is the most positive state within the waveform epoch. For waveforms with exactly two states, such as the single transition waveform, the terms low state and high state may be used in lieu of the terms state 1 and state 2, respectively." *Low state* is similarly defined. The high and low states of a waveform are necessary for the computation of waveform amplitude and all other waveform parameters that require waveform amplitude in their computation.

The determination of high and low state is done by identifying which state is the most negative and most positive out of all the possible states. As mentioned in the previous paragraph, there are several methods for identifying the states of a waveform, and the method used must be specified by the user.

State Boundaries—"The upper and lower limits of the *states* of a *waveform*. All values of a *waveform* that are within the boundaries of a given *state* are said to be in that *state*. The *state boundaries* are defined by the user." The boundaries of a state are necessary because these define the limits on the waveform values outside of which, if the waveform values exist, constitute aberration or similar waveform error. The state boundaries define the limits of the aberration regions (described subsequently), which are used in the computation of overshoot and undershoot (also described subsequently).

State Occurrence—"A contiguous region of a waveform that is bounded by the upper and lower state boundaries of a state, and whose duration equals or exceeds the specified minimum duration for state attainment. The state occurrence consists of the entire portion of the waveform that remains within the boundaries of that state. State occurrences are numbered as ordered pairs (s, n), where s is the number of the state, and n is the number of the occurrence of that particular state within the waveform epoch. In a given waveform epoch, when the waveform first enters a state s_1, that state occurrence is $(s_1, 1)$. If and when the waveform exits that state, that state occurrence is over. If and when the waveform next enters and remains in state s_1, that state occurrence would be labeled $(s_1, 2)$, and so on. Thus, the state occurrences for a single pulse, as shown in Figure [2], are $(s_1, 1)$, $(s_2, 1)$, $(s_1, 2)$. Note that a waveform can exit one state occurrence without (necessarily) immediately entering another state occurrence, that is, the waveform state between state occurrences can be undefined for some time interval, for example, during transitions and in the case of transients (such as, runt pulses)." The definition of a pulse waveform requires that the pulse waveform meet certain requirements. One of these requirements is that the pulse waveform attains certain states and another is that the waveform remains in each of those states for a certain duration. *State occurrence* refers to a contiguous region of a waveform wherein its values are within the boundaries of that state. A waveform is in a state for all instants for which the waveform is within the boundaries of that state. A state occurrence, however, requires that the waveform stay within the boundaries of that state for a minimum duration. This duration is defined by the user. Durations of a state less than this user-specified value are not considered state occurrences. The waveform enters and exits a state by crossing the state boundary. For example, if the waveform values are approaching a state from more negative values than that of the state level, once the waveform crosses the lower state boundary, the waveform is said to be in that state. Once the waveform exits that state by either taking on values more negative than the lower state boundary or more positive than the upper state boundary, the waveform is no longer in that state. This term is useful for differentiating runts and glitches from rectangular pulses in a waveform.

Reference Level—"A user-specified level that extends through all instants of the waveform epoch. [Mesial, proximal, and distal lines are deprecated terms because (1) line refers to consideration of and computations using a pictorial waveform representation whereas waveforms today are primarily stored in digital waveform representations and computation and viewing are done using a computer; (2) the terms mesial, proximal, and distal refer to user-defined reference levels and it is not necessary to have redundant definitions for these reference levels; (3) the terms proximal and distal cannot be used unambiguously to describe lines or points on either side of a transition of a step-like waveform because they depend on whether the step-like waveform is for a positive pulse or a negative pulse. In other words, for (3), the proximal line and points if referenced to the 10% reference level will appear to the left of a transition for a positive pulse and to the right for a negative pulse.]" These are user-specified levels that are constant throughout the waveform epoch and are specified using the same unit of measure that is assigned to a state. Reference level is usually expressed as a percent reference level, which is shown next.

Percent Reference Level—"A reference level specified by

$$y_{x\%} = y_{0\%} + \frac{x}{100}(y_{100\%} - y_{0\%})$$

where $0\% < x < 100\%$, $y_{0\%}$ = level of low state, $y_{100\%}$ = level of high state, and $y_{0\%}$, $y_{100\%}$, and $y_{x\%}$ are all in the same unit of measurement. Commonly used reference levels are 0%, 10%, 50%, 90%, and 100% (see Figs. 1–3)." Reference amplitude values were called *reference lines* in the withdrawn standards, such as the *10% reference line*. Again this is a graphical representation and not representative of a physical device. The Standard uses the term *percent reference level*, and this value is referenced to the amplitude of the waveform (the same way

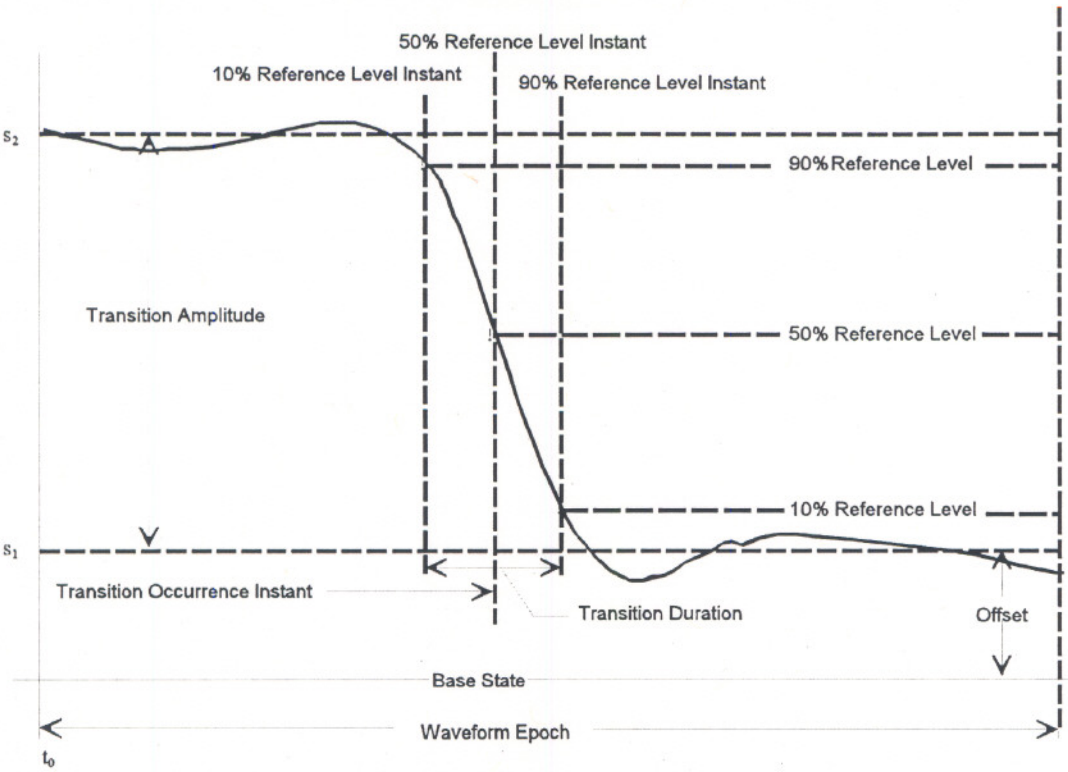

Fig. 3. Negative-going transition.

reference line was referenced to the waveform amplitude). Similarly, it was necessary to redefine the instants that the waveform crosses the reference levels. The withdrawn standard used the term *point*, which again is a graphical representation. The Standard uses *reference level instant*, which will be mentioned subsequently. The usage presented in the Standard unambiguously ties the reference level to its occurrence

Reference Level Instant—"An *instant* at which the *waveform* intersects a specified *reference level*." This term describes the instant of occurrence for any user-specified level in the waveform. This is the most fundamental parameter for all other time parameters, such as pulse duration and transition duration.

Post-Transition Aberration Region—"The interval between a user-specified instant and a fixed instant, where the fixed instant is the first sampling *instant* succeeding the 50% reference level instant when the waveform value is within the state boundaries of the state succeeding the 50% reference level instant. The user-specified instant occurs after the fixed instant and is typically equal to the fixed instant plus three times the transition duration." A similar definition exists for the pretransition aberration region. Overshoot and undershoot are a type of aberration that are commonly quoted in product specifications or used to discuss the quality of a pulse. SCOPT defined regions in the waveform in which aberrations would be defined as *overshoot* and *undershoot*. Consequently, a single-transition waveform may exhibit four of these special aberrations, pretransition overshoot, pretransition undershoot, post-transition overshoot, and post-transition undershoot.

IV. Frequently Measured Waveform Parameters

The following parameters are the waveform parameters most commonly quoted or specified by manufacturers to describe their equipment, most commonly used to describe and compare instrument performance, and most frequently measured. The following algorithms are abbreviated versions of the algorithms given in IEEE Standard 181-2003.

Waveform Amplitude—"The difference between the levels of two different states of a waveform." The Standard contains two subordinate definitions: one for signed waveform amplitude and the other for unsigned waveform amplitude. The latter is the absolute value of the former. The amplitude of a waveform is the waveform parameter from which all other level parameters are computed and from which most time parameters are computed.

Algorithm for signed waveform amplitude

(1) Determine s_1 and s_2 using a method described in Clause 5.2 of the Standard.

(2) The waveform amplitude A is the difference between $\mathrm{level}(s_2)$ and $\mathrm{level}(s_1)$.

  (2.1) For positive-going transitions, A is given by

$$A = \mathrm{level}(s_2) - \mathrm{level}(s_1).$$

  (2.2) For negative-going transitions, A is given by

$$A = \mathrm{level}(s_1) - \mathrm{level}(s_2).$$

This is the difference between the level occuring later in time and the level occuring earlier in time.

Waveform Aberration—"The algebraic difference in waveform values between all corresponding instants in time of a waveform and a reference waveform in a specified waveform epoch." Aberrations are ubiquitous waveform features that heretofore have not had a well-defined method for their calculation. Although the reference waveform used here is a ramp-type waveform, the user has the option of selecting or defining a different reference waveform.

Algorithm

(1) Calculate the $x1\%$ and $x2\%$ reference levels as described in Clause 5.3.2. Typically used reference levels are the 10% and 90% reference levels.

(2) Calculate the reference level instants, $t_{x1\%}$ and $t_{x2\%}$, as described in Clause 5.3.3, for the reference levels determined in Step (1).

(3) Determine the pre-transition aberration region and *post-transition aberration region* as described in Clause 5.3.5 and exclude those regions in the calculation of waveform aberration.

(4) Calculate the trapezoidal reference waveform, $r(t)$, unless otherwise specified, as the reference waveform for calculating waveform aberrations.

(4.1) Calculate the slope through the reference levels and reference level instants of the *waveform* using

$$S = \left(\frac{y_{x2\%} - y_{x1\%}}{t_{x2\%} - t_{x1\%}}\right).$$

(4.2) Calculate the reference level instants, $t_{0\%}$ and $t_{100\%}$ that will be used to generate $r(t)$ in Step (5).

(4.2.1) The reference levels and their associated reference level instants of the reference waveform should be chosen such that the slope of the line through these points is a close fit to the corresponding waveform values.

(4.2.2) Compute the $t_{100\%}$ reference level instant using

$$t_{100\%} = t_{x2\%} + \frac{\text{level}(s_2) - y_{x2\%}}{S}.$$

(4.2.3) Compute the $t_{0\%}$ *reference level instant* using

$$t_{0\%} = t_{x1\%} + \frac{\text{level}(s_1) - y_{x1\%}}{S}.$$

(5) Generate the trapezoidal reference waveform, $r(t)$, using

$$r(t_n) = \begin{cases} y_{0\%}, & \text{for } t_n < t_{0\%} \\ S(t_n - t_{0\%}) + y_{0\%}, & \text{for } t_{0\%} \le t_n \le t_{100\%} \\ y_{100\%}, & \text{for } t_n > t_{100\%}. \end{cases}$$

(6) The waveform aberrations are calculated as the maximum positive and negative deviation of the measured waveform from the reference waveform and are presented as a percentage of the waveform amplitude. Calculate waveform aberration using

$$W_a = \begin{cases} \left(\frac{\max\{y_n - r(t_n)\}_{T_{ab}}}{y_{100\%} - y_{0\%}}\right) 100\% \\ \left(\frac{\min\{y_n - r(t_n)\}_{T_{ab}}}{y_{100\%} - y_{0\%}}\right) 100\%. \end{cases}$$

where T_{ab} is the interval over which the waveform aberration is being calculated and n is the discrete time index of the waveform.

Transition Occurrence Instant—"The first 50% reference level instant (see Clause 5.3.3.1), unless otherwise specified, on the transition of a step-like waveform" (see Figs. 1–3). These are the instants in the waveform at which the transitions are referenced. This parameter is necessary, for example, for determining pulse duration and transition duration.

Algorithm

(1) Calculate the reference levels as described in Clause 5.3.2.

(2) Calculate the reference level instant for $y_{x\%}$ using linear interpolation

$$t_{x\%} = t_{x\%-} + \left(\frac{t_{x\%+} - t_{x\%-}}{y_{x\%+} - y_{x\%-}}\right)(y_{x\%} - y_{x\%-}).$$

where $t_{x\%-}$ and $t_{x\%+}$ are two consecutive sampling *instants* corresponding to data nearest in value to $y_{x\%}$ such that $y_{x\%-} \le y_{x\%} \le y_{x\%+}$. If there is more than one reference level instant, the reference level instant closest to the 50% reference level instant (see Clause 5.3.3.1) is used, unless otherwise specified.

Overshoot and Undershoot—Overshoot—"A waveform aberration within a post- or pre-transition aberration region that is greater than the upper state boundary for the associated state level." Undershoot—"A waveform aberration within a post- or pre-transition aberration region that is less than the lower state boundary for the associated state level. [Preshoot is a deprecated term because 'pre' is a temporal prefix and 'shoot,' in this context, refers to a level parameter.]" *Overshoot* and *undershoot* are ambiguous terms. *Undershoot* is often called *preshoot*, which is describing an amplitude in terms of time. *Overshoot* and *undershoot* are often interchanged when discussing the aberrations immediately preceding or succeeding a negative-going transition. The Standard eliminates this ambiguity by specifying whether the overshoot and undershoot occur before or after a transition. Accordingly, there are four possible terms, pretransition overshoot, pretransition undershoot, post-transition overshoot, and post-transition undershoot. Overshoot and undershoot have historically been the most often quoted waveform aberration. Computing the post-transition overshoot as the maximum error regardless of when that error occurs relative to the transition is not consistent with typical usage in which overshoot is restricted to a region near the transition. To be consistent with the present use of the terms *overshoot* and *undershoot*, the waveform around the transition is separated into pretransition and post-transition aberration regions. The duration of these regions equals three times the transition duration, unless otherwise indicated. For the pretransition aberration region, the interval starts at the 10% reference level instant and extends toward the initial instant (the first time of the waveform epoch). For the post-transition aberration region, the interval starts at the 90% reference level instant and extends toward the final instant (the last time of the waveform epoch).

Algorithm

(1) Determine $\text{level}(s_1)$ and $\text{level}(s_2)$ using a method described in Clause 5.2 of the Standard and define the upper boundary and lower boundary for the states corresponding to these levels.

(2) Determine the maximum and minimum waveform values, $y_{\max}$ and $y_{\min}$.

(3) Calculate the waveform amplitude A as described in Clause 5.3.1.

(4) Calculate the $x1\%$ and $x2\%$ reference levels and the 50% reference level as described in Clause 5.3.2. Typically used *reference levels* are the 10% and 90% *reference levels*.

(5) Calculate the reference level instants, $t_{x1\%}$, $t_{50\%}$ and $t_{x2\%}$, as described in Clause 5.3.3, for the reference levels determined in Step (4).

(6) Calculate the transition duration, for the reference level instants determined in Step (5), as described in Clause 5.3.4.

(7) Calculate the overshoot and undershoot in the pretransition aberration region.

(7.1) Calculate the last instant t_{pre} that occurs before $t_{50\%}$ when the waveform exits the upper (lower) *state boundary* of the low state (high state) for a positive-going (negative-going) transition using the method described in Clause 5.3.3.

(7.2) Define the pretransition aberration region as that between $t_{\text{pre}} - 3t_{10\%-90\%}$ and t_{pre} (or as determined by the user).

(7.3) Search the pretransition aberration region for the maximum value $y_{\max,\text{pre}}$ and the minimum value $y_{\min,\text{pre}}$. $y_{\max,\text{pre}}$ is the maximum y_i in the pretransition aberration region and $y_{\min,\text{pre}}$ is the minimum y_i in the pre-transition aberration region.

(7.4) If $y_{\max,\text{pre}}$ is equal to or less than the upper state boundary of s_1 (s_2) for a positive-going (negative-going) transition, then the overshoot in the pretransition aberration region O_{pre} is zero; otherwise, compute the percentage overshoot in the pretransition aberration region using

$$O_{\text{pre}}(\%) = \frac{y_{\max,\text{pre}} - \text{level}(s_k)}{|A|}100\%$$

where $\text{level}(s_k) = \text{level}(s_1)$ for a positive-going transition and $\text{level}(s_k) = \text{level}(s_2)$ for a negative-going transition.

(7.5) If $y_{\min,\text{pre}}$ is equal to or greater than the lower state boundary s_1 (s_2) for a positive-going (negative-going) transition, then the undershoot in the pretransition aberration region U_{pre} is zero; otherwise, compute the percentage undershoot in the pretransition aberration region using:

$$U_{\text{pre}}(\%) = \frac{\text{level}(s_k) - y_{\min,\text{pre}}}{|A|}100\%.$$

(8) Calculate the overshoot and undershoot in the post-transition aberration region.

(8.1) Calculate the first instant t_{post} that occurs after $t_{50\%}$ when the waveform enters the lower (upper) state boundary of the high state (low state) for a positive-going (negative-going) transition using the method described in Clause 5.3.3.

(8.2) Define the post-transition aberration region as that between t_{post} and $t_{\text{post}} + 3t_{10\%-90\%}$ (or as determined by the user).

(8.3) Search the post-transition aberration region for the maximum value $y_{\max,\text{post}}$ and the minimum value $y_{\min,\text{post}}$. $y_{\max,\text{post}}$ is the maximum y_i in the post-transition aberration region and $y_{\min,\text{post}}$ is the minimum y_i in the post-transition aberration region.

(8.4) If $y_{\max,\text{post}}$ is equal to or less than the upper state boundary of s_2 (s_1) for a positive-going (negative-going) transition, then the overshoot in the post-transition aberration region O_{post} is zero; otherwise, compute the percentage overshoot in the post-transition aberration region using

$$O_{\text{post}}(\%) = \frac{y_{\max,\text{post}} - \text{level}(s_k)}{|A|}100\%.$$

(8.5) If $y_{\min,\text{post}}$ is equal to or greater than the lower state boundary s_2 (s_1) for a positive-going (negative-going) transition, then the undershoot in the post-transition aberration region U_{post} is zero; otherwise, compute the percentage undershoot in the post-transition aberration region using

$$U_{\text{post}}(\%) = \frac{\text{level}(s_k) - y_{\text{min,post}}}{|A|} 100\%.$$

Pulse Duration [Width, Pulse]—"The difference between the first and second transition occurrence instants (see Fig. 2). [Pulse Width, full width at half maximum (FWHM), and half width at half maximum (HWHM) are, in general, deprecated terms because width is a word that denotes a spatial parameter whereas the parameter of interest is time. However, in some applications it may be desired to discuss the spatial location of a propagating pulse and its spatial distribution, i.e., pulse width in matter or space. FWHM, HWHM, and full duration at half maximum (FDHM) are deprecated terms because of the reference to the maximum value of the waveform, where the waveform amplitude may be either positive or negative and the waveform may contain noise.]" After transition duration, this is the most commonly referenced, quoted, and measured waveform parameter.

Algorithm
(1) Select a waveform epoch or subepoch that contains exactly one pulse waveform.
(2) Select the $x\%$ reference level. Typically the $y_{50\%}$ is used.
(3) Calculate the reference level instant $t_{1,x\%}$ for the $x\%$ reference level in accordance with Clause 5.3.3 for the positive-going (negative-going) transition of the waveform selected in Step (1).
(4) Calculate the reference level instant $t_{2,x\%}$ for the $x\%$ reference level in accordance with Clause 5.3.3 for the negative-going (positive-going) transition of the waveform used in Step (3) above.
(5) The pulse duration T_P is the absolute value of the difference between the reference level instants found in Steps (3) and (4):

$$T_P = |t_{2,x\%} - t_{1,x\%}|.$$

Transition Duration [Risetime, Falltime, Leading Edge, Rising Edge, Trailing Edge, Falling Edge, Time, Transition]—"The difference between the two reference level instants of the same transition (see Figs. 1 and 3). Unless otherwise specified, the two reference levels are the 10% and 90% reference levels. [The terms risetime, falltime, and transition time, although widely used, are deprecated because they are ambiguous and confusing. First, the use of the word time in this standard refers exclusively to an instant and not an interval. Also, if the first transition of a waveform within a waveform epoch happens to be a negative transition, some users may refer to its transition duration as its risetime, and some others may refer to its transition duration as its falltime. If the use of these deprecated terms is required, then risetime is synonymous with the transition duration of a positive-going transition, and falltime is synonymous with the transition duration of a negative-going transition. If the upper and lower state boundaries of the two states are not the user-defined reference levels (for example, the 10% and 90% reference levels), then the duration of a transition is not equal to the transition duration.]" This is the most commonly quoted, referenced, and measured waveform parameter. The bandwidth of an instrument is often approximated by BW $\approx 0.35/t_d$, where BW is bandwidth and t_d is transition duration.

Algorithm
(1) Calculate the reference level instant $t_{x1\%}$ for the $x1\%$ reference level in accordance with Clause 5.3.3 that is nearest to the 50% reference level instant, unless otherwise specified.
(2) Calculate the reference level instant $t_{x2\%}$ for the $x2\%$ reference level in accordance with Clause 5.3.3 that is nearest to the 50% reference level instant, unless otherwise specified.
(3) Calculate the transition duration $t_{x1\%-x2\%}$

$$t_{x1\%-x2\%} = |t_{x1\%} - t_{x2\%}|.$$

Transition Settling Duration—"The time interval between the 50% reference level instant, unless otherwise specified, and the final instant the waveform crosses the state boundary of a specified state in its approach to that state. [The term settling time is a deprecated term because the word time in this standard refers exclusively to an instant and not an interval.]" This is a commonly quoted parameter describing how quickly a pulse of a generator or the step response of a measurement instrument will settle to some nominally steady-state value.

Algorithm
(1) Calculate the 50% reference level, as described in Clause 5.3.2.
(2) Calculate the 50% reference level instant as described in Clause 5.3.3.
(3) Specify the state boundaries of the specified state (usually state 2).
(4) Determine the instant at which the waveform enters and subsequently remains within the specified state boundary.
(4.1) Starting at the end of the waveform epoch, check each waveform value against the specified state boundaries.
(4.2) Record the sampling instant of the first waveform value encountered that is found outside the state boundary.
(4.3) Calculate the instant that the waveform crosses the state boundary using the method described in Clause 5.3.3.

(5) Calculate the transition settling duration by finding the difference between the instant determined in Step (4.3) and the 50% reference level instant determined in Step (2).

Transition Settling Error—"The maximum error between the waveform value and a specified reference level within a user-specified interval of the waveform epoch. The interval starts at a user-specified instant relative to the 50% reference level instant." This is a less commonly used parameter than transition settling duration to describe how well a pulse of a generator or the step response of a measurement instrument will settle to some nominally steady-state value. The distinction is that this parameter determines the error within a given interval, whereas transition settling duration determines the instant when the waveform values are not within state boundaries. Waveform recorders frequently specify a maximum settling error within different time intervals from a reference instant.

Algorithm
(1) Calculate the 50% reference level instant as described in Clause 5.3.3.1.
(2) Specify which state level, $\mathrm{level}(s_1)$ or $\mathrm{level}(s_2)$, will be used to compute the transition settling error.
(3) Specify the instant t_s and corresponding waveform sample index i_s at which the interval over which the transition settling error is to be determined starts.
(4) Specify the instant t_f and corresponding waveform sample index i_f at which the interval over which the transition settling error is to be determined ends.
(5) Determine transition settling error E_{settling} using

$$E_{\mathrm{settling}} = \max\left\{\left|\frac{y_i - \mathrm{level}(s_k)}{\mathrm{level}(s_2) - \mathrm{level}(s_1)}\right|\right\}, \quad i_s \le i \le i_f$$

where $k = 1$ or 2, depending on whether the state level selected in Step (2) was s_1 or s_2.

V. Future for the IEEE Std-181-2003

The Std-181-2003 reflects terminology and analyzes for pulse measurements and metrology, which is often applied to state-of-the-art technologies. The purpose of SCOPT is to ensure Std-181 contains pertinent and useful information. Std-181 must be reballoted every five years to remain active. If you are interested in participating in the development of the Std-181, please contact the IEEE TC-10 Chairman, currently Thomas Linnenbrink (e-mail: linnenbrink@qdot.com), or the SCOPT Chairman, currently Nick Paulter (e-mail: nicholas.paulter@nist.gov).

VI. Summary

Std-181-2003 is a standard on pulse techniques and definitions that replaces the withdrawn standards IEEE-Std-181-1977 and Std-194-1977. The major improvement in the new standard has been in the clarification and updating of the definitions section and the addition of algorithms for extracting waveform parameters.

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Nicholas G. Paulter, photograph and biography not available at the time of publication.

D. R. Larson, photograph and biography not available at the time of publication.

Jerome J. Blair, photograph and biography not available at the time of publication.